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Parametric study of simulated tennis shoe treads

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Abstract

We report on friction properties between simulated tennis shoe treads created in house and a hard court tennis surface approved by the International Tennis Federation. To simulate tennis shoe tread, we use the compound N70 Nitrile Butadiene Rubber, which possesses similar physical characteristics as commercial tennis shoe treads, namely hardness, tensile strength, and elongation percentage. Into that compound we have created a series of tread patterns with various shapes, spacing, and heights. An in-house traction rig allows for the maintaining of a constant vertical load while a horizontal load is monotonically increased until our tread slips on the hard court tennis surface. Our experimental apparatus allows us to test a range of rubber compound areas and tread patterns. We performed experiments with different vertical loads and extracted both static and dynamic friction coefficients using force data supplied by load cells mounted vertically and horizontally. Variations in the compound's tread geometry lead to different friction coefficients. We also rotated our tread patterns over a range of angles and extracted associated friction coefficients. Our results have moved us closer to a better understanding of optimal tread patterns on a tennis shoe. Such results are especially of interest to us as sliding is becoming a more prominent feature of elite tennis play on hard courts.

Keywords: friction ; static friction ; kinetic friction ; tennis ; shoe treads ; mechanical test device

1. Introduction

Tennis is played on different surfaces such as clay, grass, and hard courts. The speed of the game demands complex and specific movements from its players. The evolution of the sport and the influence of the different surfaces in performance and injury risk have encouraged shoe manufacturers to design tennis shoes specific to each surface. A clear example of how specialized is the design of a shoe sole specific for tennis is shown in [1], which includes two different patterns specifically manufactured to respond to the particular needs of the player during match play.

Shoe evolution has allowed athletes to increase their court performance, giving them the ability to perform new complex dynamic movements, such as sliding on hard courts, which has been suggested [2] to reduce the player reposition time between shots. Geometry of the treads on the outsole (e.g. herringbone, dimples, pimples, and orientation of the treads), which provides for different amounts of friction with the playing surface, is the main difference between

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tennis shoes on the market designed for a specific surface. There is, however, a paucity of investigations into how shoe-tread geometry affects friction between shoe and court surface.

A previous study [3] demonstrated the effect of shoe orientation on the friction generated between shoe and tennis surface during a sliding movement, suggesting that friction depends on the vertical force applied and the shoe angle. Those results suggest an influence of the tread geometry on the shoe-surface friction, which is our interest here.

The purpose of this study was to investigate and understand the effects of different tread patterns of a tennis shoe on the friction generated during the shoe-surface interaction. The effect of the vertical load and the variation of tread geometry are especially of interest, as sliding on hard courts is becoming a more prominent feature of elite tennis. A better understanding of the shoe-surface interaction will help to determine the optimal tread patterns on a tennis shoe for a given tennis court.

2. Methodology

Experiments with a bespoke portable friction testing device were conducted on a commercially available hard-court surface sample. As developed and fully described in [4], the device consists of three main components: a sled, a pneumatic ram, and a test shoe slider (see Fig. 1). A shoe slider with a test sample is attached to the sled with the desired orientation. Weights are positioned on top of the sled until the desired normal force is reached. A solenoid valve is then activated, opening the pneumatic cylinder that provides a horizontal force, which increases until the test sample transitions from a state of rest to a state of motion. The maximum sliding length is 0.1 m. A load cell and a linear variable differential transformer (LVDT) in the horizontal direction provide the measurements necessary to determine the applied horizontal force. A data acquisition device samples the load cell and LVDT signals at 1666.67 Hz, which are then transformed into values of force and displacement.

Two different outsole tread patterns of a commercial "all-court" tennis shoe manufactured by Babolat and a sample of a commercially available "smooth rubber" (N70 Nitrile Butadiene Rubber) with mechanical properties similar to a commercial tennis shoe [4] were tested. Additional experiments were performed on two rubber samples (N70 Nitrile Butadiene Rubber) with different machined tread patterns (see Fig. 2). The "machined treads" are 3.5 mm thick, 1.5 mm tall, and spaced 1.5 mm from each other. For the "holed rubber," the machine-punched holes are 2 mm in diameter. Two sections of the Babolat outsole were removed, an interior "Babolat pimples" section designed for grip while a player is mostly upright and an outside edge "Babolat dimples" section that is supposed to enhance a player's slide. The pimples are 6.3 mm × 12.1 mm; the dimples are 2 mm × 6.5 mm with a depth of 2.1 mm.

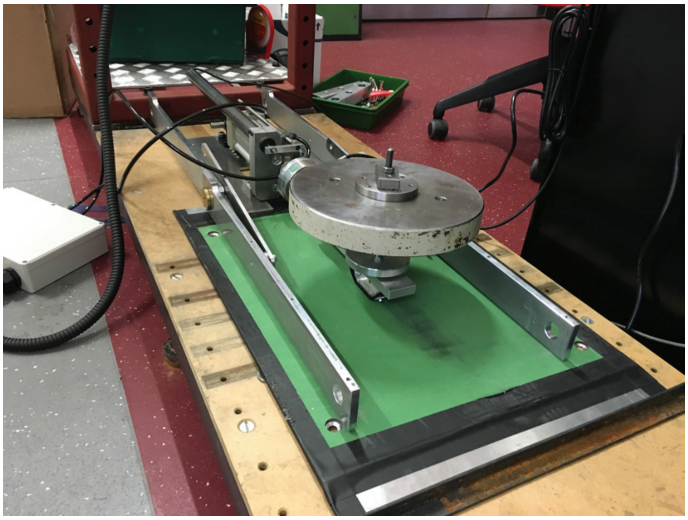

Fig. 1. Portable testing device with tread sample in place. The green tennis court surface measures 0.42 m × 0.52 m. A 10-kg mass is attached to the top of the sample.